 <p>CEOS Committee on Earth Observation Satellites</p>	<p>Analysis Ready Data</p> <p><i>For Land</i></p>	<p>Product Family Specification: Normalised Radar Backscatter</p>
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Document status

For Adoption as: Product Family Specification, Normalised Radar Backscatter

This Specification should next be reviewed at: September 2018.

Proposed revisions may be provided to:

lsi@lists.ceos.org

Document history

Version	Date	Description of change	Author
0.0.2	23-03-2017	Zero Draft based on materials discussed in and leading up to LSI-VC-3, provided by SEO and others.	Lewis
0.1.0	18-04-2017	Various revisions to structure	Lewis
1.0.0	18-04-2017	Included material provided by Brian Killough / SEO reflecting input from a range of SAR experts / users.	Lewis
1.0.1	20-04-2017	Edits reflecting feedback from SEO, change to the figure / table in 'guidance'; removed item 4.2 which appeared redundant; moved reference to definitive ephemeris to a note under item 4.1; added reference to speckle under table 3 (radiometric corrections)	Lewis and Killough
2.0.0	30-08-2017	Feedback incorporated, circulated to LSI-VC	Lewis
2.1.0	6-09-2017	Feedback from ESA included	Lewis
2.1.1	6-09-2017	Edits rolled in	Lewis
3.0	02-02-2018	Feedback from the teleconference (06/12/2018) and post teleconf (emails) included	Siqueira
3.1	03-04-2018	Nuno Miranda (ESA) comments addressed (uncertainty information to be required at the threshold level – 3.4 Radiometric corrections (Accuracy), split sensor acquisition mode)	Siqueira
3.1.1	12-04-2018	Ake Rosenqvist (JAXA) comments (split sensor acquisition mode into acquisition and processing parameters, include "global incidence angle")	Siqueira
3.1.1	04-06-2018	Feedback received from Dr. Ben Lewis	Siqueira

3.2	07-08-2018	(process table update) Feedback from the "SAR ARD definition Team" before and at IGRASS 2018	Siqueira
3.2	21-08-2018	Feedback on the 2nd SAR ARD definition Team teleconference (20/08/2018): add a sentence on 1.19 that the radiometric performance metadata should be provided for each of the polarization channel when available (from Ake Rosenqvist)	Siqueira
3.2.1	14-12-2018	clarification about per pixel NESZ provision for each channel when noise removal is implemented	Chapman

Description

Product family title: Radar Backscatter (CARD4L-Radar)

Applies to: *Data collected by synthetic aperture radar*

sensors. **Abstract**

Synthetic aperture radar imagery enables a growing range of applications of radar data that draw on multiple observations from multiple instruments and viewing modes. The necessary data preparation steps are well established in the literature and have been demonstrated in practice (see Guidance section). This CARD4L product specification reflects these data preparation steps.

CARD4L-Radar product will enable a set of new, generalist, users to access and apply these data in geographical analyses to produce improved products, thus increasing the impact of CEOS Agencies' data. The CARD4L product is not relevant to interferometric studies.

Definitions

NRB	Normalised Radar Backscatter
Ancillary Data	Ancillary data is data other than instrument measurements, originating in the instrument itself or from the satellite, required to perform processing of the data. They include orbit data, attitude data, time information, spacecraft engineering data, calibration data, data quality information and data from other instruments.
Auxiliary Data	Auxiliary data is the data required for instrument processing, which does not originate in the instrument itself or from the satellite. Some auxiliary data will be generated in the ground segment, whilst other data will be provided from external sources.
MTF	Modulation Transfer Function
Spatial Resolution	The highest magnification of the sensor at the ground surface
Spatial Sampling Distance	Spatial sampling distance is the barycentre-to-barycentre distance between adjacent spatial samples on the Earth's surface.

Requirements

1. General Metadata

These are metadata records describing a distributed collection of pixels. The collection of pixels referred to must be contiguous in space and time. General metadata should allow the user to assess the overall suitability of the dataset, and must meet the following requirements:

	Item	Threshold (minimum) requirements	Target (desired) requirements
1.1	Traceability	Not required.	Data must be traceable to SI reference standard. For further information see, for example, http://l-a-b.com/information/traceability/
1.2	Metadata machine readability	Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use.	As threshold, but metadata is formatted in accordance with ISO 19115-2.
1.3	Data collection time	The start and stop time of data collection is identified in the metadata, expressed in date/time, to the second, with the time offset from UTC unambiguously identified.	Acquisition time for each pixel is identified (or can be reliably determined) in the metadata, expressed in date/time at UTC, to the second.
1.4	Geographical area	The surface location to which the data relates is identified, typically as a series of four corner points, expressed in an accepted coordinate reference system (e.g., WGS84).	The geographic area covered by the observations is identified specifically, such as through a set of coordinates of a closely bounding polygon. The location to which each pixel refers is identified (or can be reliably determined) expressed in projection coordinates with reference datum.
1.5	Coordinate reference system	The metadata lists the coordinate reference system that has been used.	As threshold
1.6	Map projection	The metadata lists the map projection that has been used, and any relevant parameters required in relation to use of data in that map projection.	As threshold
1.7	Geometric correction	The metadata describes the geodetic correction methods used, including reference database and ancillary data such as elevation model(s) and	As threshold

		reference chip-sets. DOIs are used.	
1.8	Geometric accuracy	A single-figure estimate of the Geometric accuracy is provided. The user is not necessarily provided with results of geometric correction processes pertaining to the dataset.	The metadata includes metrics describing the assessed geodetic accuracy of the data, expressed units of the coordinate system of the data. Accuracy is assessed by independent verification (as well as internal model-fit where applicable). Uncertainties are expressed as root mean square error (RMSE) or Circular Error Probability (e.g., CEP90, CEP95).
1.9	Instrument	The instrument used to collect the data is identified in the metadata.	As threshold, but including a reference to the relevant CEOS Missions, Instruments and Measurements Database record.
1.10	Acquisition parameters	Acquisition parameters details: - look direction (L, R) - polarizations - resolution (range x azimuth) - orbit direction of data-take (ascending or descending)	As threshold.
1.11	Processing parameters	Processing parameters details: - pixel spacing (range x azimuth) - number of looks and equivalent number of looks	As threshold.
1.12	Sensor calibration	Sensor calibration details / list of scientific papers and articles websites describing the calibration approach/method used	As threshold.
1.13	Radiometric accuracy	Not required. The general metadata does not include specific information on the radiometric accuracy of the data. OR, A global uncertainty estimate is provided	The metadata includes metrics describing the assessed absolute radiometric accuracy of the data, expressed as absolute radiometric uncertainty relative to a known reference standard (e.g., pseudo-invariant calibration sites) <i>Note 1: for example, this may come from comparison with rigorously collected in situ measurements</i>
1.14	Algorithms	All algorithms, and the sequence in which they were applied in the generation	As threshold, but only algorithms that have been published in a peer-reviewed journal <i>Note: It is possible that high quality corrections are applied through</i>

		process, are identified in the metadata.	<i>non-disclosed processes. CARD4L does not per-se require full and open data and methods.</i> DOIs for each algorithm are identified in the metadata. The versions of the algorithms are identified.
1.15	Ancillary data	The metadata identifies the sources of ancillary data used in the generation process, ideally expressed as DOIs. <i>Note 1: ancillary data includes DEMs, etc. data sources</i>	As threshold, but the ancillary data is also available for free online download, contemporaneously with the product.
1.16	Processing chain provenance	Not required.	The metadata includes a description of the processing chain used to generate the product, including the versions of the software used.
1.17	Data access	The metadata identifies the location from where the product can be retrieved, expressed as a DOI. <i>Note 1: Manual and offline interaction action (e.g. log in) may be required.</i>	The metadata identifies an online location from where the data (including any available new records) can be consistently and reliably retrieved by a computer algorithm without any manual intervention being required. <i>Note 1: Some manual interaction action may be required <u>in the first instance</u> ('one off' basis) to establish ongoing access to the data.</i>
1.18	Overall data quality	Not applicable	TBD. There is a perceived need for machine-readable metrics describing the overall quality of the data, however the specifications for these are yet to be determined. If there is not a clear case and clear specifications for such metadata, then "Overall data quality" will be removed.
1.19	Performance Indicators	Provide performance indicators on resolution, SLR, NESZ. Those are not to be estimated on each product, but estimated once and annotated on all products. That information should be provided for each polarization channel when available.	As threshold.

2. Per-pixel metadata

The following minimum metadata specifications apply to each pixel. Whether the metadata are provided in a single record relevant to all pixels, or separately for each pixel, is at the discretion of the data provider.

Per-pixel metadata should allow users to discriminate between (choose) observations on the basis of their individual suitability for application.

	Item	Threshold (minimum) requirements	Target (desired) requirements
2.1	Metadata machine readability	Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use.	As threshold, but metadata is formatted in accordance with relevant international standards (ISO 19115-2).
2.2	No data	Pixels or grid cells that do not correspond to an observation ('empty pixels') are clearly flagged	As threshold.
2.3	Layover	Layover flags or mask is provided	As threshold.
2.4	Shadow	Shadow flags or mask is provided	As threshold.
2.5	Local Incidence Angle	Local Incidence angle image is provided	As threshold.
2.6	Global Incidence Angle	Global incidence angle is provided	As threshold.
2.7	Digital Elevation Model	Digital Elevation Model used for Radiometric Terrain Correction	As threshold.
2.8	Noise Equivalent Sigma0	Noise equivalent σ^0 used for Noise Removal, if applied, for each channel	Noise equivalent σ^0 for each channel
2.9	Number of Looks	Number of looks for each pixel provided for multi-look products	As threshold.

3. Radiometric corrections

The following requirements must be met for all pixels in a collection. The requirements indicate the necessary outcomes and to some degree the minimum steps necessary to be deemed to have achieved those outcomes. Radiometric corrections must lead to normalised measurement(s) of backscatter intensity.

	Item	Threshold (minimum) requirements	Target (desired) requirements
3.1	Measurements	Gamma-0 (γ^0) backscatter coefficient is provided for each polarisation (e.g. HH, HV, VV, VH) Note: transformation to the logarithm decibel scale is not required or desired as this step can be easily completed by the user if necessary.	As threshold.
3.2	Noise removal	Optional	Thermal noise removal and image border noise removal (when applicable) to remove overall scene noise and scene edge artefacts, respectively.

3.3	Terrain Corrections	<p>Adjustments are made for terrain by modelling the local illuminated reference area using the preferred choice of peer reviewed models to produce a radiometrically terrain corrected (RTC) γ_0.</p> <p>Metadata references:</p> <ul style="list-style-type: none"> ● a citable peer-reviewed algorithm, ● technical documentation regarding the implementation of that algorithm expressed as DOIs ● the sources of ancillary data used to make corrections. <p>Note 1: examples of technical documentation include an Algorithm Theoretical Basis Document, product user guide, etc.</p> <p>Note 2: requirement for metadata are better placed in 1.13 and 1.14 (Radiometric accuracy and Algorithms).</p>	<p>Require resolution of DEM no worse than (TBD) the SAR backscatter resolution when applying terrain corrections.</p> <p>Require validation that any change in DEM or landcover between the date of the DEM determination and the date of the SAR backscatter acquisition does result in violating the radiometric or geometric accuracy.</p>
3.4	Accuracy	Uncertainty (e.g., bounds on γ_0) information is provided. SI traceability is achieved	As threshold.

Note: Speckle filtering is not addressed here, as this process removes noise but alters the original backscatter values. Some users may desire this processing step, but it is not accepted as a common product for the majority of applications.

4. Geometric corrections

Geometric corrections must place the measurement accurately on the surface of the Earth (that is, geolocate the measurement) allowing measurements taken through time to be compared.

	Item	Threshold (minimum) requirements	Target (desired) requirements
4.1	Accuracy	<p>a) Sub-pixel accuracy is taken to be less than or equal to 0.2-pixel radial root mean square error (rRMSE) or equivalent in Circular Error Probability (CEP) relative to a defined reference.</p> <p>b) A given data provider shall use the same DEM (DEM of their choice) to ensure consistency of the data stack.</p>	<p>a) Sub-pixel accuracy is achieved relative to an identified absolute independent terrestrial referencing system (such as a national map grid).</p> <p>b) A DEM with comparable or better resolution to the resolution of the output ARD imagery shall be used.</p> <p>c) A consistent gridding / sampling</p>

	<p>c) A consistent gridding / sampling frame is used, including common cell size, origin, and nominal sample point location within the cell (centre, ll, ur)</p> <p><i>Note 1. Relevant metadata must be provided under 1.7 and 1.8 (Geometric correction and Geometric accuracy)</i></p> <p><i>Note 2. Accurate geolocation is a prerequisite to radar processing to correct for terrain. To enable interoperability between radar sensors absolute accuracy is required. Orbit ephemeris updates (precise ephemeris) are required prior to any orthorectification steps to ensure accuracy.</i></p>	<p>frame is necessary to meet this requirement.</p> <p><i>Note 3. Relevant metadata must be provided under 1.7 and 1.8 (Geometric correction and Geometric accuracy)</i></p>
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Guidance

This section aims to provide background and specific information on the processing steps that can be used to achieve analysis ready data. This Guidance material does not replace or over-ride the specifications.

Introduction to CARD4L

What is CEOS Analysis Ready Data for Land (CARD4L) products?

CARD4L products have been processed to a minimum set of requirements and organized into a form that allows immediate analysis with a minimum of additional user effort. These products would be resampled onto a common geometric grid (for a given product) and would provide baseline data for further interoperability both through time and with other datasets.

CARD4L products are intended to be flexible and accessible products suitable for a wide range of users for a wide variety of applications, including particularly time series analysis and multi-sensor application development. They are also intended to support rapid ingestion and exploitation via high-performance computing, cloud computing and other future data architectures. They may not be suitable for all purposes, and are not intended as a 'replacement' for other types of satellite products.

When can a product be called CARD4L?

The CARD4L branding is applied to a particular product once:

- that product has been assessed as meeting CARD4L requirements by the agency responsible for production and distribution of the product.
- that assessment has been peer reviewed by the CEOS Land Surface Imaging Virtual Constellation in consultation with the CEOS Working Group on Calibration and Validation.

Agencies or other entities considering undertaking an assessment process should contact the co-leads of the Land Surface Imaging Virtual Constellation ([hyperlink](#)).

A product can continue to use CARD4L branding as long as its generation and distribution remain consistent with the peer-reviewed assessment.

What is the difference between Threshold and Target?

Products that meet all threshold requirements should be immediately useful for scientific analysis or decision-making.

Products that meet target requirements will reduce the overall product uncertainties and enhance broad-scale applications. For example, the products may enhance interoperability or provide increased accuracy through additional corrections that are not reasonable at the *threshold* level.

Target requirements anticipate continuous improvement of methods and evolution of community expectations which are both normal and inevitable in a developing field. Over time, *target* specifications may (and subject to due process) become accepted as *threshold* requirements.

Procedural examples

Processes to produce Threshold Normalised Radar Backscatter CARD4L-Radar

The following general process would typically be applied to produce CARD4L-Radar Threshold.

- Apply the best possible orbit parameters to give the most accurate product possible. These will have been projected to an ellipsoidal model such as WGS84. In order to achieve the threshold levels of geometric accuracy required of CARD4L it is generally considered that precise orbit determination will be required.
- Apply instrument calibrations to produce Beta-naught values
- Apply geometric terrain corrections (ortho-rectify)

Note that the geometric and radiometric corrections should be undertaken in a single step to minimise the number of resampling steps.

These steps have been applied, for example, in global ALOS PALSAR products as described by Shimada *et. al* (2014) and Small (2011). Through the use of a rigorous terrain-based model of the geometry of illumination and backscatter improved terrain flattening is achieved and issues of lay-over and foreshortening are addressed. The resulting data are more highly comparable through time, across viewing geometries (ascending / descending) and between sensors. Note that these steps alone do not produce, for example, the meta-data expected of a CARD4L product.

Specific examples

The following examples are included to illustrate how corrections may be made for some datasets. They are not intended to be comprehensive or exclusive. Additional examples may be added in time where data providers or processors are able to offer them.

Processes to produce Threshold Radar Backscatter CARD4L-Radar for Sentinel-1

These are based on 'typical' processing of Sentinel-1 data, and can be completed using the Sentinel Tool Box provided by ESA (courtesy Brian Killough, SEO and others listed in the graphic).

- Orbit Updates applied to include the definitive ephemeris for improved geolocation

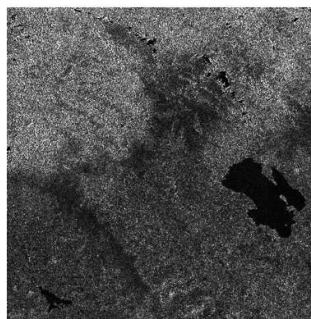
- Remove GRD Border Noise - Removes processed artifacts at scene edges where non-zero noise values exist.
- Remove Thermal Noise – Removes thermal noise using thresholds. Not a significant correction, but commonly used by most users.
- Radiometric Calibration - Converts raw data to backscatter intensity (beta-0 output)
- Radiometric Terrain Correction - Radiometric normalization (terrain flattening) using DEM data (gamma-0 output)
- Speckle Filter – Removes noise but adds blurring to features and reduces resolution. This may be applied as an “advanced ARD” product for select users.
- Geometric Terrain Correction - Orthorectification using DEM topography data (gamma-0 output in preferred grid projection)

A summary of these steps is given below:

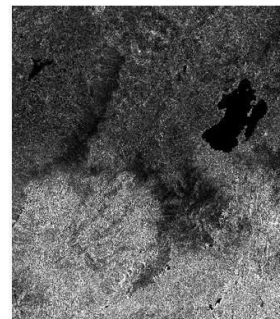
Step	Description	CEOS ARD	Google	Zheng-Shu Zhou (CSIRO)	Ben Lewis (GA)
1	Orbit Updates	x	x	x	x
2	GRD Border Noise	x	no	no	x
3	Thermal Noise	x	x	x	no
4	Radiometric Calibration	x	x	x	x
5	Radiometric Terrain Correction	x	x	x	x
6	Speckle Filter	no	no	x	no
7	Orthorectification	x	x	x	x



Unprocessed - VH Intensity
Lake: Laguna de Tota
Location: Sogamoso, Colombia



Steps 1 to 6
Gamma-0, VH Intensity



Step 7 - Orthorectification
Gamma-0, VH, UTM-WRS84

(Image courtesy B. Killough, SEO)

Reference papers

The following papers provide scientific and technical guidance:

Hoekman D. and Reiche, J. Multi-model radiometric slope correction of SAR images of complex terrain using a two-stage semi-empirical approach. *Remote Sensing of Environment*, **156** (2015), pp. 1-10.

Shimada, M., Itoh, T., Motohka, T., Watanabe, M., Shiraishi, T., Thapa, R., and Lucas, R. New global forest/non-forest maps from ALOS PALSAR data (2007–2010). *Remote Sensing of Environment* **155** (2014) pp13–31.

Small D. Flattening Gamma: Radiometric Terrain Correction for SAR Imagery, *IEEE Transactions on Geoscience and Remote Sensing*, 2011, Vol. 49 (8), pp. 3081-3093.

Shimada, M. Ortho-Rectification and Slope Correction of SAR Data Using DEM and Its Accuracy Evaluation. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. Dec. 2010, vol. 3, no. 4, pp 657 – 671.

Small D., Miranda N., Meier E. [2009] (presentation), Local Incidence Angle Considered Harmful, *Proc. of CEOS SAR 2009 Workshop*, Pasadena, California, USA, Nov. 17-19, 2009.

D. Small, N. Miranda and E. Meier, "A revised radiometric normalisation standard for SAR," 2009 *IEEE International Geoscience and Remote Sensing Symposium*, Cape Town, 2009, pp. IV-566-IV-569.
doi: 10.1109/IGARSS.2009.5417439